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Publication date	2017-05-01
Original Citation	Alexander, J. K., Morrissey, P. E., Yang, H., Yang, M., Zhao, Y., Rensing, M., O'Brien, P. and Peters, F. H. (2017) 'Butterfly packaged low-linewidth optical comb source', Electronics Letters, 53(9), pp. 615-616. doi:10.1049/el.2017.0378
Type of publication	Article (peer-reviewed)
Link to publisher's version	10.1049/el.2017.0378
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Download date	2023-05-07 17:12:16
Item downloaded from	http://hdl.handle.net/10468/5772

Butterfly packaged low-linewidth optical comb source

J. K. Alexander, P. E. Morrissey, H. Yang, M. Yang, Y. Zhao, M. Rensing, P. O'Brien, and F. H. Peters

A packaged optical comb source is demonstrated. A low linewidth optical comb source is designed and fabricated. The device is packaged in a 7 pin high speed butterfly package with an SMA connector for RF modulation and fibre pigtail. Fibre coupling efficiency is estimated at 43%. The packaged comb source is shown to have a linewidth of 300 kHz for the comb line set when modulated at 4 GHz, with 8 comb lines within 3 dB of each other. The prototype packaged comb source has applications in high bandwidth telecommunications.

Introduction: Bandwidth use in optical communications is increasing at an accelerated rate. Global IP traffic is expected to reach 2.3 ZB by 2020 [1]. As a result, spectrally efficient communications are being utilised to increase the information spectral density (Gbps/Hz) and is a valuable current topic of research. The optimal use of current communications infrastructure is essential to meet the demand for communications bandwidth in the immediate future. Wavelength division multiplexing (WDM) requires spectrally inefficient guard bands separating each communication channel [2]. These guard bands can be removed by using a coherent optical comb to generate the channels, creating a superchannel [3]. A superchannel can lead to a significant increase in information spectral density so that Tbps superchannels can then be created using less total fibre bandwidth. Gain-switching is a method of producing optical combs whereby a laser is directly modulated by a high power RF signal [4], although, rapid modulation of the laser carriers leads to an increase in phase noise due to modulation of the refractive index. Injection-locking, whereby a laser's frequency is locked to that of another laser, is shown to reduce phase noise in gain-switched lasers [5], as well as enhancing the laser resonance [6].

In this letter we present a low-linewidth optical comb source, which was designed, fabricated, and packaged in a butterfly package. The packaged device uses an injection-locked gain-switched laser to produce an optical comb. The package features 7 DC pins, RF SMA connector, and fibre pigtail. Figure 1 shows the optical comb source in a prototype package. Such a package has great potential for the future of a superchannel communications system.

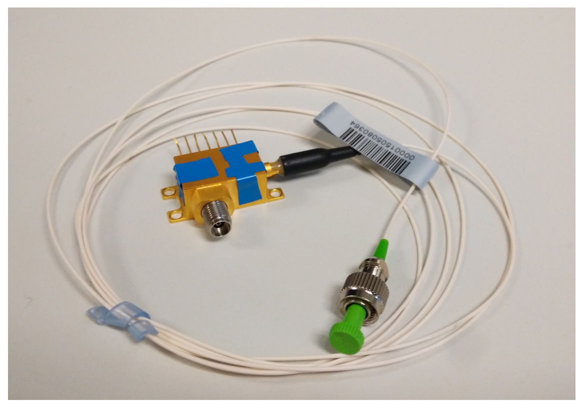

Figure 1: Butterfly package for optical comb source, featuring 7 DC pins, RF SMA connector, and fibre pigtail.

Device design & fabrication: The device is a two section Slotted Fabry-Perót (SFP) [7] laser of total length 1350 µm integrated with with a shorter SFP laser of length 680 µm. The longer SFP is referred to as the master laser, the shorter SFP the slave. On-chip injection-locking is performed as in [8]. The master SFP has a 600 µm gain section, with a 760 µm slotted mirror section. The mirror section consists of 8 periodically spaced slots, with slot width 0.88 µm, period 108 µm, and slot depth of 1.7 µm. The slave SFP has a 250 µm gain section, and a 430 µm mirror section. The mirror consists of 5 periodically spaced slots with the same slot width, period, and depth as before. The SFPs are coupled via a 15 µm long waveguide section. A schematic of the device is shown in Figure 2 with each section labeled.

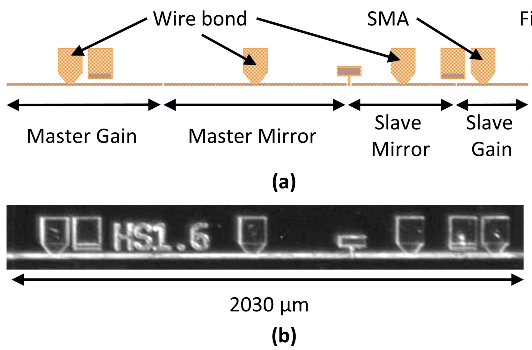

Figure 2: (a) Device schematic with sections labeled. Contact pads for the DC pin wire bonds and SMA connector are indicated, as well the facet used for fibre coupling. (b) Microscope image of device.

Commercially available lasing material designed for emission at 1550 nm was used to fabricate the device. The material consists of 5 compressively strained AlGaInAs quantum wells on an n-doped (100) InP substrate, with a total active region thickness of 0.41 µm. The upper p-doped cladding consists of a 0.2 µm InGaAs cap layer, followed by 0.05 µm of InGaAsP, lattice matched to 1.62 µm of InP. The ridge width is 2.5 µm with a height of 1.7 µm. A 3 µm etch through the quantum wells was used to access the n region to create a top level n-contact. Standard lithographic techniques were used to define device features. The fabrication methods used are similar to those described in [5].

The device was packaged in a 7-pin high-speed butterfly package. A thermoelectric cooler (TEC) was included in the package to maintain a stable temperature under use. Wire-bonds were used to connect the Master Gain, Master Mirror, and Slave Mirror contact pads to DC pins. The Slave Gain contact pad was wire-bonded to a micro-strip line connecting to an RF SMA connector. The SMA connector allows for RF modulation of the Slave Gain section. A fibre pigtail coupled light out of the device from the Slave Gain facet. The lensed optical fibre inside the package can be seen in Figure 3.

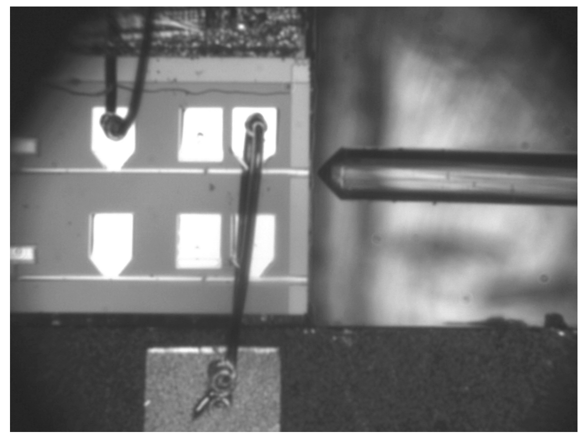

Figure 3: Microscope view of inside the butterfly package showing wire-bonds and lensed optical fibre.

Results: The package was mounted on a butterfly mount (Laser 2000, model 203) and was maintained at 20 °C using the TEC. An estimate of the coupling efficiency of the fibre was measured by injecting 0 dBm of optical power at 1550 nm into the device. The Slave section was reverse biased at −2 V and the total reverse current was recorded. The current generated as a result of absorption (total reverse current minus dark current) was converted to optical power (assuming 1 photon creates 1 electron) giving a coupling efficiency of 43%. Losses can be accounted by mode size mismatch and fibre positioning error.

DC bias was applied to all four sections of the device. A bias tee was used to apply simultaneous RF & DC bias to the Slave Gain section. Optical spectra were recorded using an optical spectrum analyzer (OSA) with a wavelength resolution of 0.015 nm. DC bias currents of 70 mA, 25 mA, 5 mA, and 40 mA were applied to the Master Gain, Master Mirror, Slave Mirror, and Slave Gain sections respectively. A 4 GHz 25 dBm RF signal was applied to the Slave Gain section. An S_{11} measurement performed with a vector network analyzer (VNA) was used to estimate that 36% of the RF power was absorbed by the device. The optical spectrum was recorded and can be seen in Figure 4. Eight comb lines can be seen to be within 3 dB of each other.

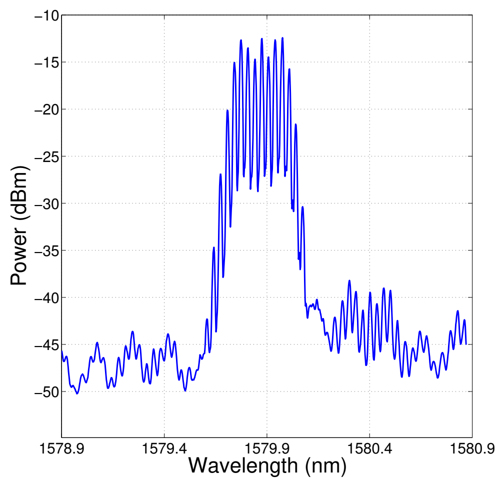

Figure 4: 4 GHz optical comb produced from butterfly packaged device showing 8 comb lines within 3 dB of each other.

The linewidth of the device was measured using the delayed self-heterodyne (DSH) method outlined in [5]. The fibre length for the delay was 50 km giving a resolution of <2 kHz for the measurement. The linewidth measurement can be see in Figure 5.

The full-width half-max (FWHM) of the measurement in Figure 5 is approximately 600 kHz. The linewidth of the device is taken as half the FWHM value, giving a linewidth of 300 kHz.

Conclusion: A prototype butterfly packaged low-linewidth optical comb source is demonstrated. Fibre coupling efficiency was estimated at 43%. The device

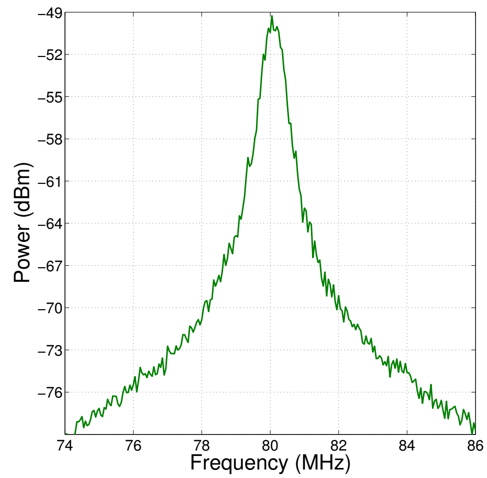

Figure 5: Linewidth measurement using the DSH method. 50 km delay fibre was used, along with a 80 MHz acousto-optic modulator to shift the delayed signal. The full-width half-max is measured as approximately 600 kHz.

can produce an optical comb with 8 comb lines within 3 dB of each other at 4 GHz, with a linewidth for the comb set of 300 kHz. The device design monolithically integrates two lasers and uses on-chip injection locking in the generation of the optical comb. This packaged comb source has applications in the future of WDM superchannel systems.

This work was supported by the Science Foundation Ireland under grants 12/RC/2276 (IPIC) and SFI10/CE/I1853 (CTVR).

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